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Microbial copper uptake rates governed by pH in hot spring ecosystems

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Microbes can incorporate copper (Cu) from their environment as a micronutrient. Copper uptake is controlled by bioavailability which is influenced by geochemical context including pH, temperature, aqueous chemistry, and subsequent metal speciation [1: 3]. Little is known about microbial copper uptake rates by thermophilic microorganisms. We examined microbial Cu uptake rates in five Yellowstone hydrothermal springs across a diverse oxygen gradient using the novel methodology, metal stable isotope probing (MSIP) [4]. Followed by dissolved oxygen and Cu speciation as calculated using the WORM interface to EQ3 [5], pH determined microbial Cu uptake. The highest uptake rate of 32 ± 7 nmol $d^{-1}L^{-1}$ occurred at the pH 5.81 source followed by a sharp decrease in uptake rates as pH exceeded 6, consistent with an optimal pH 6 for Cu uptake observed in previous culture experiments [1]. Increased dissolved oxygen partially controlled microbial Cu uptake. Higher Cu uptake rates occurred in oxic outflow channels compared to anoxic-suboxic sources within the same spring, except for the pH 5.81 suboxic source with a Cu uptake rate three times higher than its oxic outflow. The lowest microbial Cu uptake rate occurred at the pH 8.81 spring anoxic source, where > 99% of copper speciated as CuO^o. Copper predominated as Cu^{2+} free ion in the pH 5.81 spring source that exhibited the highest microbial Cu uptake rate. Despite other acidic springs dominated by Cu^{2+}, their microbial Cu uptake rates did not exceed 14 nmol $d^{-1}L^{-1}$. In conclusion, MSIP indicated that thermophilic microbes in the Yellowstone hydrothermal system take up copper faster at pH ~6, behavior also seen in fresh water microalgae [1], especially if copper primarily speciated as Cu^{2+} in oxic conditions (Figure 1). Further work includes modeling microbes' metabolic pathways and correlating them with microbial Cu uptake rates using distance-based redundancy analysis statistical methods [6].

[1] Mehta et al. 2002. *J. Environ. Health.* 37:399-414. [2] Xu et al. 2012. *L&O.* 57:293-304. [3] Semeniuk et al. 2016. *Front. Mar. Sci*. 3:78. [4] Cox et al. 2014. *Mar. Chem.* 166:70-81. [5] Boyer et al. 2024. *Senodo*. [6] Dixon. 2003. *J VEG SCI.* 14:927-930.

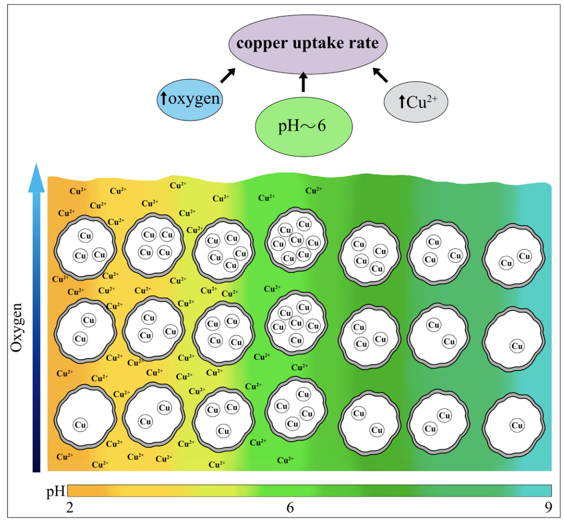

Figure 1. Microbial Cu uptake rate illustration. More Cu inside the microbial cell represents higher uptake.